STUDY ON RATIONAL GROUND PARAMETERS EVALUATION METHOD FOR DESIGN OF TEMPORARY EARTH-RETAINING WALLS

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ABSTRACT

Tokyo-Gaikan Expressway is an important trunk road that circularly connects the areas located about 15 km away from the center of Tokyo, Japan. Chiba section, approximately 9.5 km long of this expressway makes use of semi-underground ditch structures that will mostly be constructed with an open-cut system using earth-retaining walls.

Since the construction cost of earth-retaining walls accounts for the major portion of the total project cost, the evaluation of ground parameters will greatly affect the cost. Aiming for cost reduction, it was studied on rational methods for evaluating ground parameters to be used for design purposes.

Most ground parameters are generally estimated with empirical methods, which resulted in uneconomical designs. In this study, focusing on cohesion in Pleistocene sand, which greatly influences the design, a rational ground parameter evaluation method was investigated via statistics based on triaxial compression test data of various soil types.

The deformation of earth-retaining walls during excavation was compared between the computed values using the ground parameters proposed in this study and the measured values from trial construction. As a result, it was found that these new ground parameters are sufficiently safe for construction, and they can provide great economical effect.

1. INTRODUCTION

1) Overview of the project

Tokyo Outer Ring Road is an important trunk road that circularly connects the areas located about 15 km away from the center of Tokyo (Fig. 1). Currently, the Chiba section approximately 12. 1 km long of the Road is under construction. Since the areas along the Road are being urbanized, it is planned that approximately 9.5 km of this section will be constructed in the form of a semi-underground

ditch structure, allowing an access road (National Route 298) on the ground and an expressway (Tokyo-Gaikan Expressway) below ground, and construction using the open-cut method is planned for the most part of this section (Fig. 2).

Figure 1. Location map.

2) Issues involved in the project

Both the alluvial deposit and the diluvial deposit of the ground in this section are composed of an alternation of strata of the sandy soil and the cohesive soil, and the aquifers are under pressure by water heads located near the ground surface. Thus, the ground conditions are relatively poor (Fig. 3).

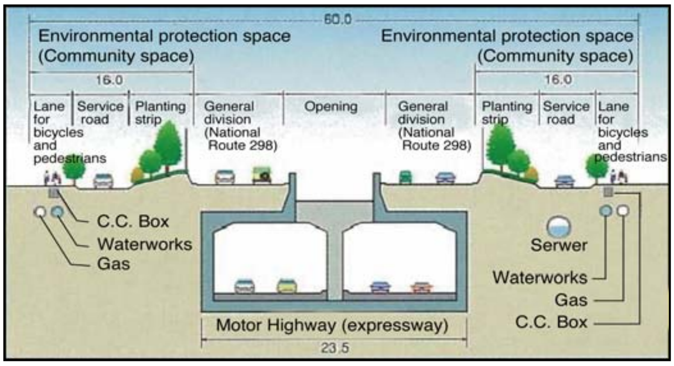
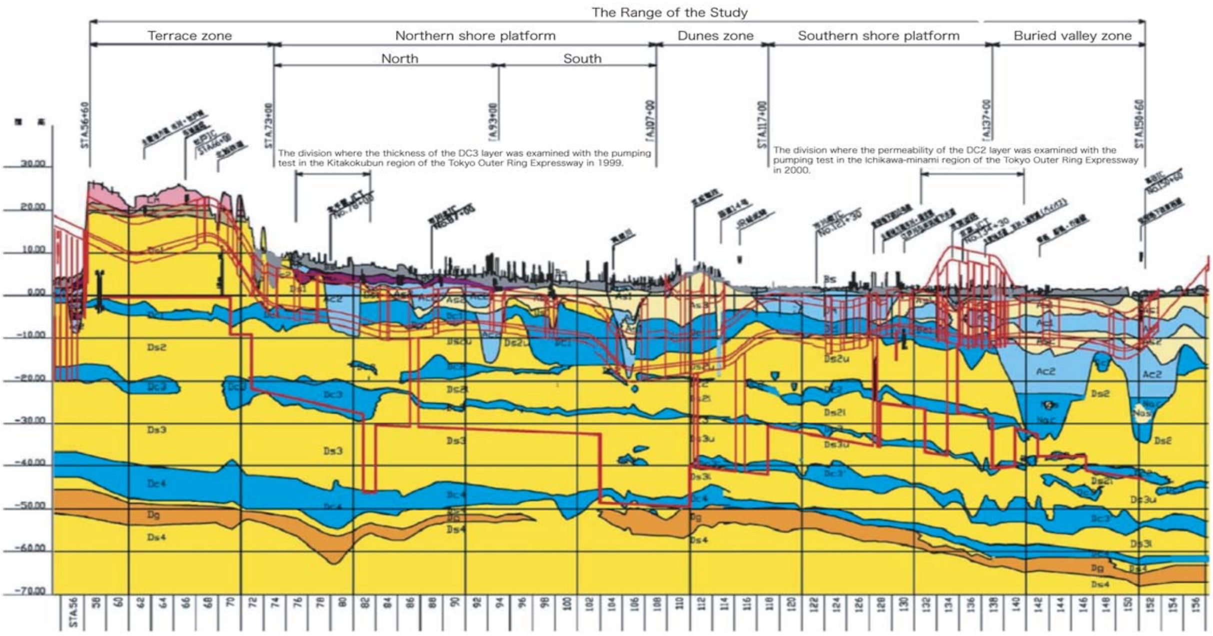


Figure 2. Typical ditch structure cross-section.

Under such conditions, when excavating the ground to construct structure, it is necessary to take countermeasures against subsidence of the surrounding ground, heaving of the bottom, and leakage of water, and thus, it is planned that earth-retaining walls will be used as temporary structures in the open-cut



Bold red line shows the embedded depth of earth retaining wall

Figure 3. Soil components in vertical section.

method. While the strength of the ground is low in this section, since the width and the depth of the excavation is large, it is likely that large-sized earth-retaining walls will have to be installed.

To construct earth-retaining walls at lower costs, the design embedment length should be shortened. Particularly, in designing temporary structures, ground parameters greatly affect the active earth pressure and the passive earth pressure, as well as the stabilization of the bottom of the excavation. Therefore, when setting the ground parameters, appropriate evaluation of the results of the soil survey greatly contributes to economic efficiency.

In this report, the ground parameters (cohesion (c), angle of internal friction (φ), and modulus of deformation (E)), which are used for designing earth-retaining walls, were focused, and the natural ground was properly evaluated to present more rational design, while maintaining a sufficient level of safety.

2. BACKGROUND OF THE STUDY

1) Conventional method for setting ground parameter

Ground parameters can be estimated by the N-value from the results of the standard penetration test or obtained by the laboratory soil test.

Table 1. Ground parameters from test site.

Soil type	c（kN／m²）	φ（°）	E（MN／m²）
Ap	20.0	0.0	6.8
Ac2	25.0	0.0	8.0
As2	0.0	35.0	9.2
Dc1	125.0	0.0	80.0
Ds2u	0.0	35.0	124.0

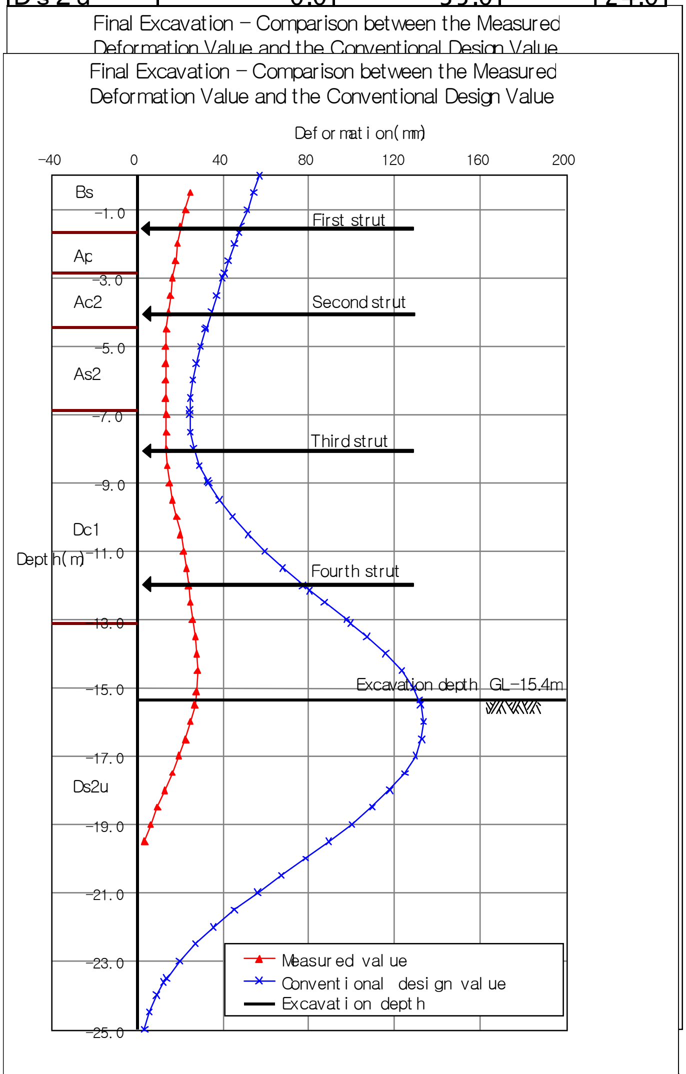


Figure 4. Comparison of earth-retaining walls displacement. (Measured values and calculated values using the conventional method)

Normally, in design, the angle of internal friction (φ) of the cohesive soil and the cohesion (c) of the sandy soil are often not expected, and the test results are not used without change. It is often the case that the cohesive soil and the sandy soil are set such that φ=0 and c=0, respectively, to ensure a higher level of safety.

First, in this study, the above section was divided into 5 blocks (terrace zone, northern shore platform, dunes zone, southern shore platform, and buried valley zone) based on their strata

characteristics, and the design ground parameters in the section were set for each block as below:

a) The average value of the results from the triaxial compression tests obtained through boring sampling was used for the cohesion (c) of the cohesive soil. The cohesion (c) of the sandy soil was not taken into account.

b) The average value of the results from the triaxial compression tests used for setting the cohesion was used for the angle of internal friction (φ) of the sandy soil. The angle of internal friction (φ) of the cohesive soil was not taken into account.

c) The modulus of deformation (E) was set by multiplying the N-value by a coefficient for both the cohesive soil and the sandy soil (28N MN/m^2).

While the ground parameters set by this method show conservative strength, there is room for improvement in terms of economic efficiency.

In the above section, the open-cut method is being employed for the northern shore platform as a trial construction. In this construction, the displacement of earth-retaining walls was measured, and the actual displacement of earth-retaining walls obtained from this site was compared with the estimated displacement calculated based on the ground parameters (Table 1) set over the past years by the above method (Fig. 4).

The results show that the displacement of earth-retaining walls obtained from the ground parameters set by the above method is greater than the actual displacement, confirming that the design ground parameters are sufficiently safe.

In light of the above results, based on the premise of safety, this report explores new ground parameters that properly evaluate the natural ground and proposes more economical values.

3. COHESION (C) IN THE DILUVIAL SANDY DEPOSIT

1) Soil types and ground parameters to be examined

Since the ground parameters to be determined will be actually used for design and construction purposes, the soil types and the ground parameters having greater impact on designing earth-retaining walls were focused and examined.

The results of the estimate showed that the cohesion (c) of the diluvial deposit (6 layers of Ds1, Dc1, Ds2, Ds2u, Dc2, Ds2l) located near the surface to which the floor of the body is attached is sensitive to design, among other ground parameters of each soil.

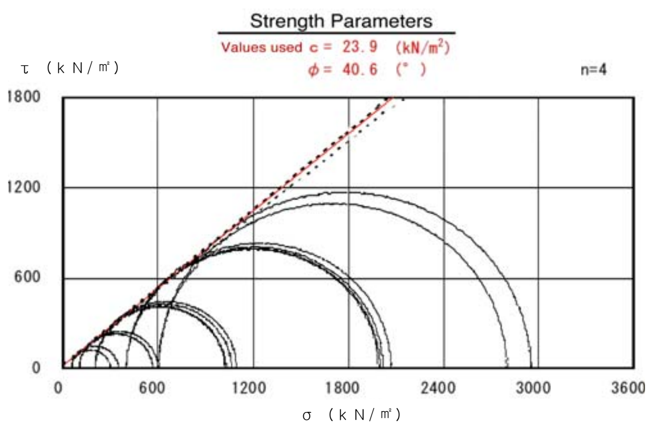


Figure 5. Triaxial compression test result of Ds2u layer from test site.

2) Results of the triaxial compression tests

While the cohesion (c) of the sandy

soil is often ignored in design, there are cases in which it is not negligible in the case of the diluvial sandy deposit.

The results of the triaxial compression tests accumulated in the section were reviewed to see if the cohesion (c) could be taken into account. The method of least squares was applied to the Mohr's circles obtained from the triaxial compression tests to draw a rapture envelope.

The triaxial compression test (Consolidated Drained: CD condition) was conducted on the Ds2u layer at the test construction site, and the results are shown in Fig 5 as an example. It was confirmed that the cohesion (c) of the sandy soil, which is often ignored, could be expected in the section (c = 27.8 kN/m^2). The same results were obtained from other sandy soil layers (Ds1, Ds2u, Ds2l).

4. REZONING

1) Resetting of the soil layers

The generation process and the particle size distribution of the ground were focused, and the soil layers in the section were redefined and grouped into 9 blocks (Fig. 6).

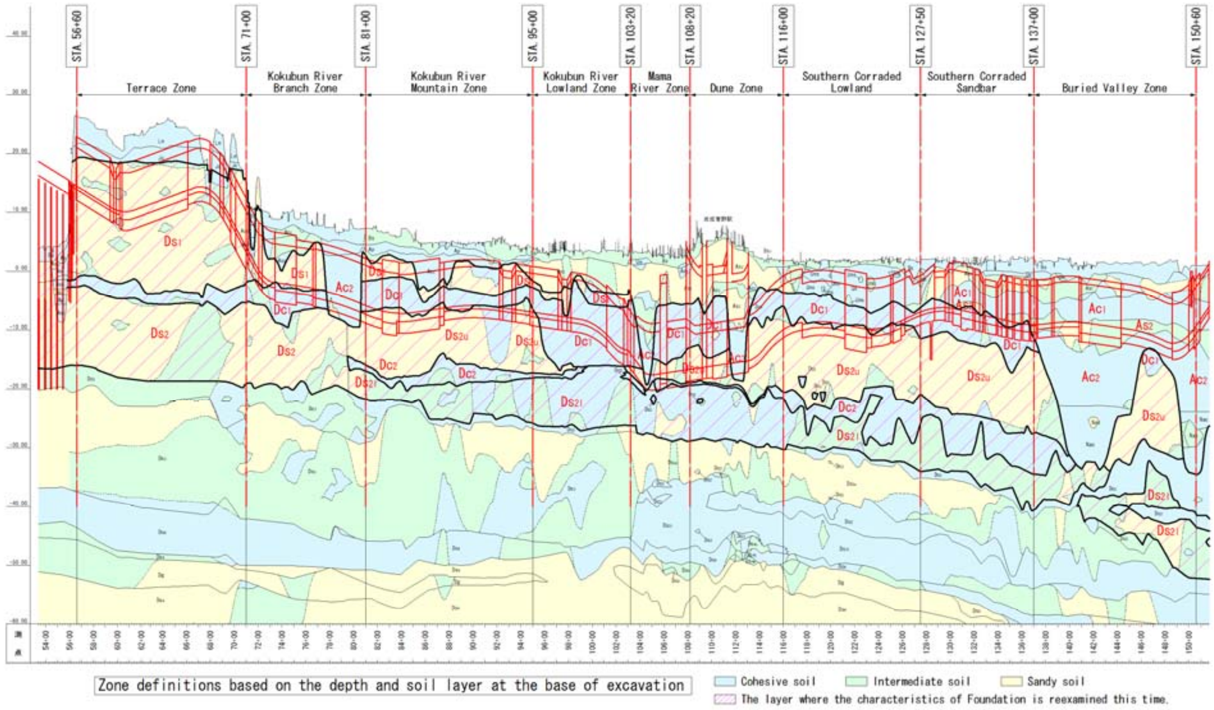


Figure6 . New soil composition.

2) Redefining of the soil types

In addition to the cohesive soil and the sandy soil, another soil type "intermediate soil" having characteristics of both of the above two soils was defined.

Focusing on the sand content ratio, the fines content ratio, and the plasticity index, each soil type was defined as follows: basically, the cohesive soil was defined as having a sand content ratio less than 50%, a fines content ratio greater than 50%, and a plasticity index greater than or equal to 30; the intermediate soil defined as having a sand content ratio greater than or equal to 50% and less than 80%, a fines content ratio greater than or equal to 20% and less than 50%, and a plasticity index less than 30; and the sandy soil defined as having a sand content ratio greater than 80% and a fines content ratio less than 20% (Fig. 7).

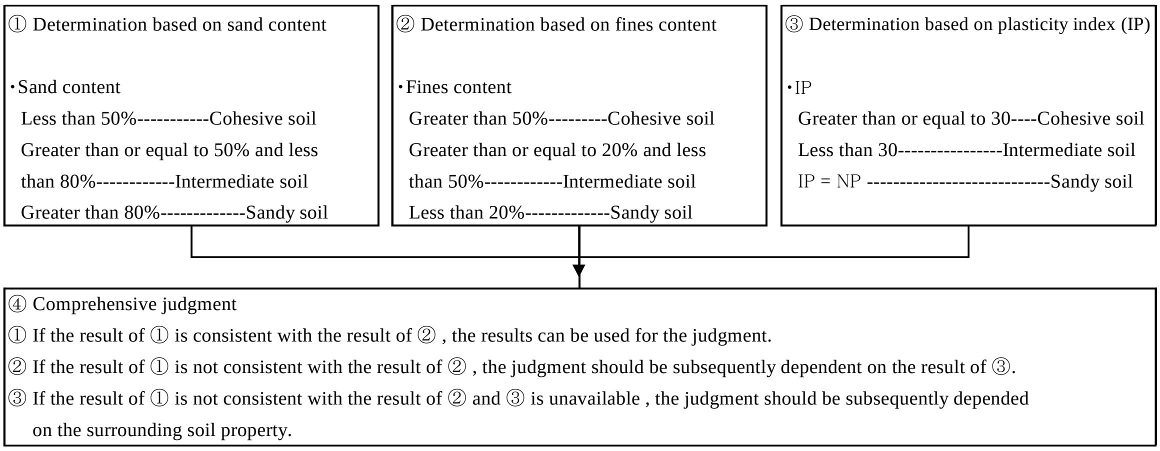


Figure 7. Soil component classification method.

5. STATISTICAL PROCESSING ON THE RESULTS OF THE TRIAXIAL COMPRESSION TESTS (COHESION (c))

Normally, in the method for performing statistical processing on the ground parameters used for design, if there is a plurality of values as data, abnormal values are excluded from the results of the triaxial compression tests conducted through boring sampling and the simple mean value of the results is used. However, it is desirable in terms of design that statistical processing be conducted in view of other aspects including the ground variation and the spatial variation.

Since boring sampling could be implemented before the ground excavation, many tests through boring sampling were conducted in the section, and data had thus been accumulated (Unconsolidated Undrained: UU test: approximately 140, CD test: approximately 190). In this study, such data was utilized to propose new design ground parameters.

Normally, as shown in the following, the average value of the data (m) and the standard deviation (σ) are used in the statistical processing method in order to obtain the design value from a plurality of values as data:

Design value=$m \pm \alpha\sigma$ (α: correction factor） (1)

If the value obtained by adding the corrected standard deviation to the average value is set to

be the design value, the degree of safety will be reduced accordingly. Thus, such value is not adopted in the study.

In this study, a new design value (c) is calculated according to the following equation, while setting the correction factor to be 1/2:

$$\text{Design value} = m - \sigma/2 \qquad (2)$$

Fig. 8 shows an example of design values.

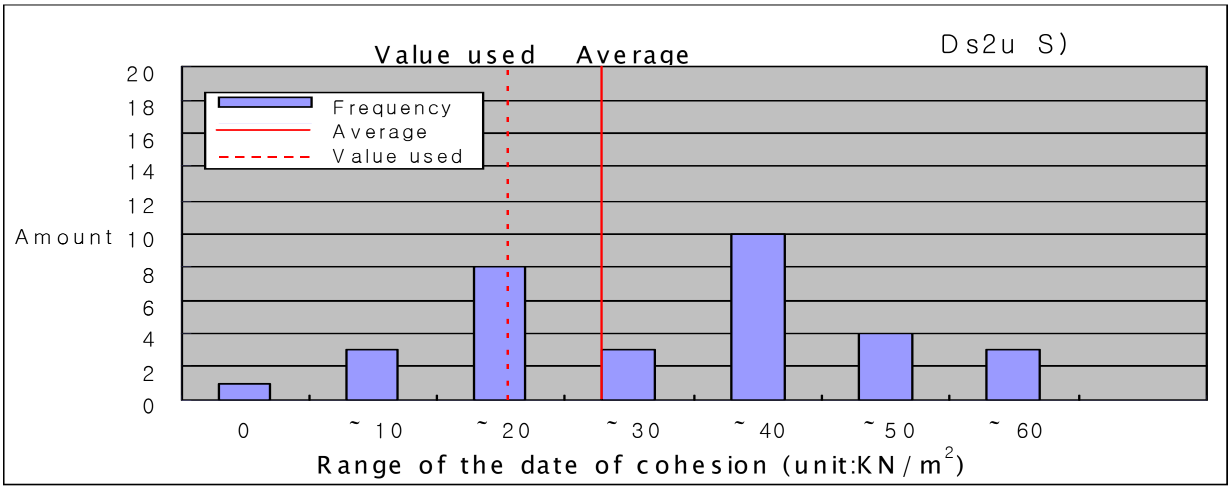


Figure 8. Example of design value (Ds2u(s)).

6. COMPARISON BETWEEN VALUES OBTAINED FROM TRIAXIAL COMPRESSION TESTS THROUGH BLOCK SAMPLING AND DESIGN VALUE

The results of the triaxial compression tests through block sampling obtained in the test construction site were compared with the design value calculated in the above mathod.

In block sampling, since soil can be obtained from the ground in the form of a lump, undisturbed soil sample can be collected. It is fair to assume that the cohesion (c) provided by the test results obtained through block sampling evaluates the ground more properly.

Fig. 9 shows a vertical cross-sectional view of the soil components at the site. Since the results of the grain size analysis showed that the Dc1 layer could be divided into the cohesive soil

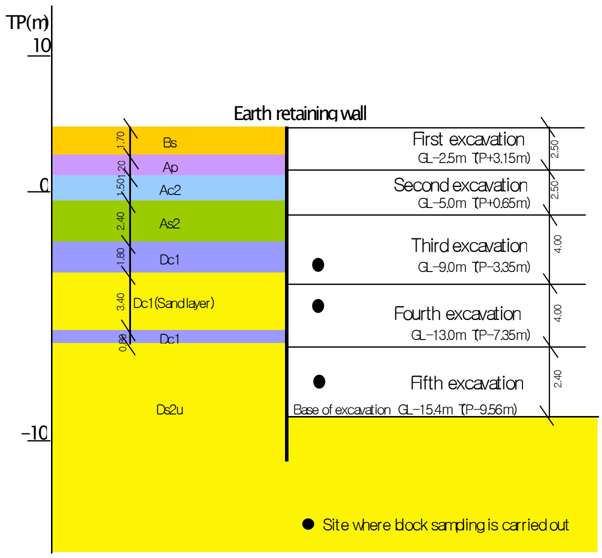


Figure 9. Soil components in vertical section of site.

layer and the sandy soil layer, the two layers were individually reviewed. The block sampling was conducted on the Dc 1 cohesive layer, Dc 1 sandy layer, and Ds2u layer. Figs. 10 and 11 show the comparison between the values obtained through the statistical processing based on equation (2) on the results of the triaxial compression tests through boring sampling implemented near the test site and the results of the triaxial compression tests through block sampling.

Fig. 10 shows the results of the test conducted on the sandy soil in the Dc 1 layer. Since the sandy soil was examined, the triaxial compression tests were based on the CD and CU (Consolidated Undrained) conditions. The results show that the statistical value obtained through boring sampling and the test values obtained through block sampling are close.

Fig. 11 shows the results of the test conducted on the intermediate soil in the Ds2u layer. Since the intermediate soil shows characteristics of both of the cohesive soil and the sandy soil, the triaxial compression tests were based on all conditions (UU, CD, CU, and CUb (CU conditions with measuring pore water pressure) conditions). The results show that all the test values obtained through

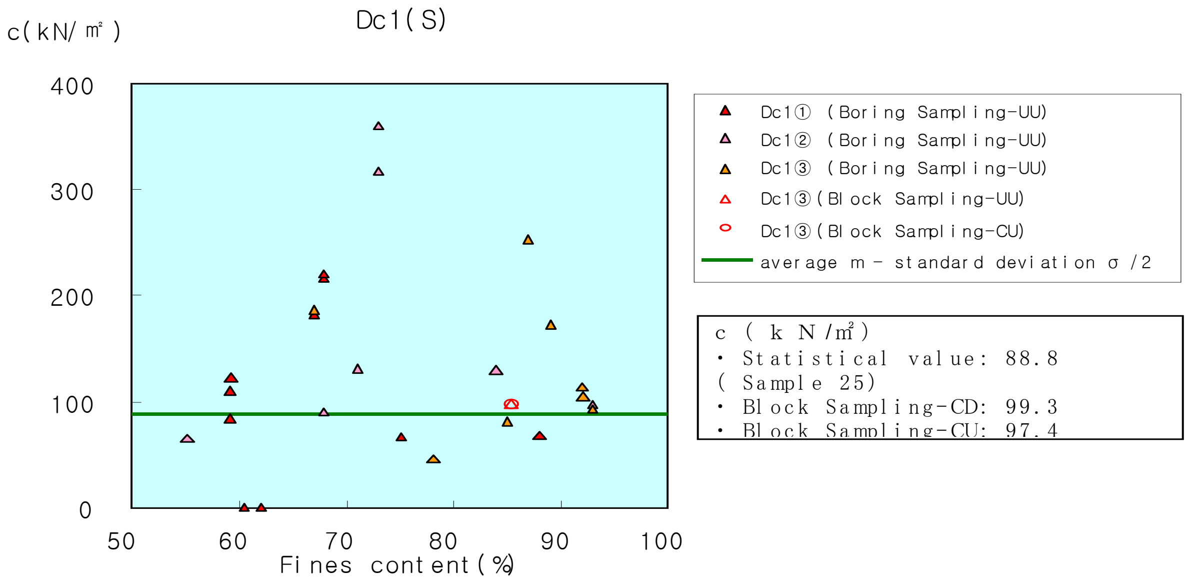


Figure 10. Comparison of block sampling and boring sampling of sandy layer Dc1 (S).

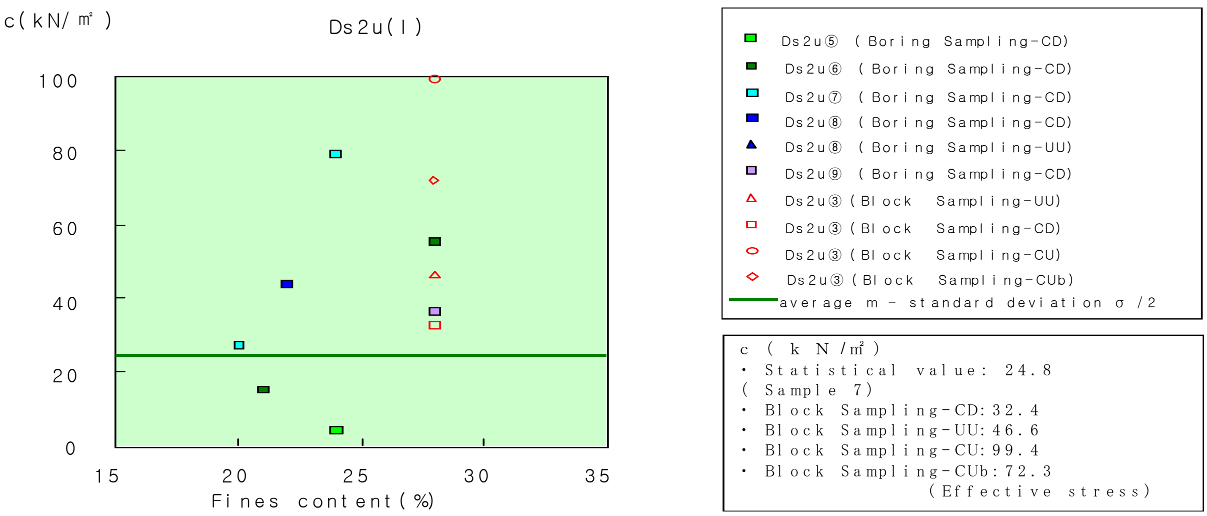


Figure 11. Comparison of block sampling and boring sampling of sandy layer Ds2u(I).

block sampling are greater than the statistical value obtained through boring sampling. Thus, it is thought in terms of design that the statistical value obtained through boring sampling indicates greater safety than the test values obtained through block sampling.

Consequently, it is concluded that the statistical processing method using equation (2) properly evaluates the existing ground.

7. SETTING OF ANGLE OF INTERNAL FRICTION (φ) AND MODULUS OF DEFORMATION (E)

The results of the sensitivity analysis confirmed that the angle of internal friction (φ) and the modulus of deformation (E) do not significantly affect design. In this study, in order to coordinate with the cohesion (c), values were accordingly set and used for design. The soil layers and soil types used herein were the same as those used for the cohesion (c). The angle of internal friction (φ) and the modulus of deformation (E) of each soil type were set as follows:

a) φ: As to the sandy and intermediate soils, the statistical processing using equation (2) was conducted on the results of the triaxial compression tests obtained through boring sampling. As to the cohesive soil, since the sensitivity is small in terms of designing earth-retaining walls, the angle of internal friction was not expected ($\varphi=0$).

b) E: For all the soil types, the statistical processing using equation (2) was conducted on the results of the triaxial compression tests obtained through boring sampling.

While the modulus of deformation (E) can be calculated by various methods such as use of the N-value or the unconfined compression test, it was determined by the triaxial compression test in this study, as in the same manner used for the cohesion (c) and the angle of internal friction (φ).

8. EVALUATION OF STRENGTH REDUCTION OF THE GROUND

After completion of the installment of earth-retaining walls, the ground was excavated to establish the body (Fig. 12). It is conceivable that since the overburden pressure is unloaded with the progress of the excavation, the ground to which the floor is attached swells over time, thereby decreasing the ground strength. To grasp the degree of this strength reduction, a swelling test was conducted on the ground. In the swelling test, sample in a saturated state was left to stand and allowed to swell, and it was then subjected to a Cub test. Also, change in shear wave velocity (Vs) was measured to grasp

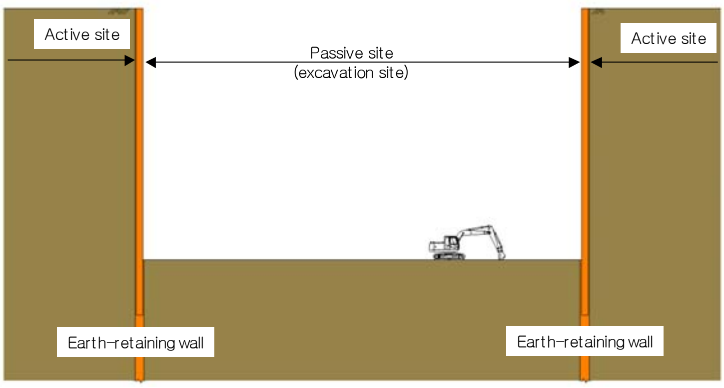


Figure 12. Illustration of ground excavation.

the swelling state over time.

To grasp the degree of the strength reduction, the peak deviator stress (q) obtained from the results of the swelling test was divided by the corresponding value (q0w) obtained from the results of the Cub test in which the sample was not allowed to swell. Figs. 13 and 14 show the relationship between the strength reduction and the elapsed time for the cohesive soil and the sandy soil, respectively.

The strength of the cohesive soil reduced by approximately 50% in the early stages, and the strength reduction remained unchanged after approximately 1 to 2 weeks from the start of the test. In contrast, little strength reduction was found in the sandy soil.

To examine this trend, the relationship between the volumetric strain and the elapsed time was focused. As the sample absorbed water, its volume increased. The volumetric strain at each of the relevant points of elapsed time was measured by using the measured shear wave velocity (Vs). Figs. 15 and 16 show the relationship between the elapsed time and the volumetric strain for the cohesive soil and the sandy soil, respectively.

The results show that the strength of the cohesive soil reduces and its volume increases over time. In contract, small change was confirmed in the volume of the sandy soil.

Thus, it is found that the strength of the cohesive soil on the passive side (excavation side) decreases over time. Note that since the angle of internal friction (φ) is

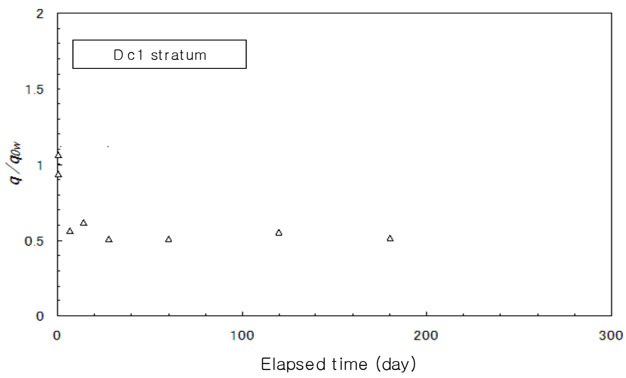


Figure 13. Strength reduction of Dc1 soil.

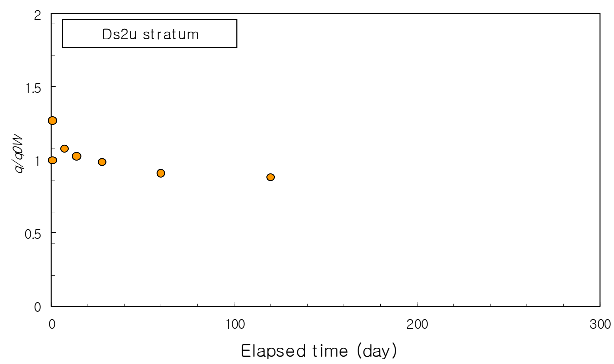


Figure 14. Strength reduction of Ds2u soil.

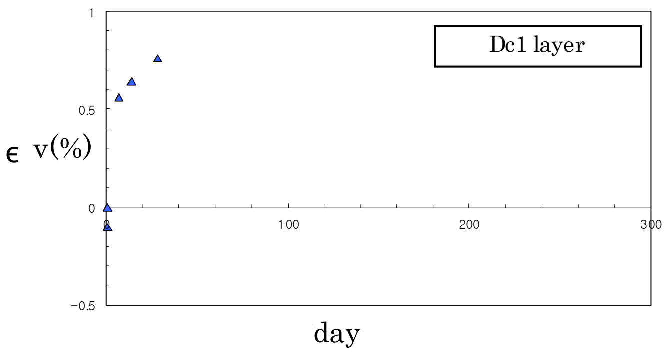


Figure 15. Volumetric strain of Dc1 layer against elapsed time

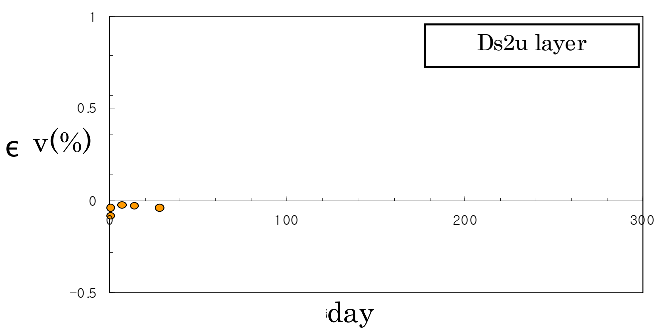


Figure 16. Volumetric strain in the Ds2u layer against elapsed time

not expected in this study, the shearing resistance is mobilized due to the cohesion (c) Namely, since the shearing resistance decreases by 50% and remains at the same level, the cohesion (c), which is taken into account in design, is set to be 50% of the value obtained by equation (2).

Since no strength reduction was found in the sandy soil, the cohesion (c) obtained by equation (2) was not reduced.

In view of safety, the cohesion (c) of the intermediate soil was reduced by 50%, as was the case with the cohesive soil.

9. SETTING OF NEW GROUND PARAMETERS

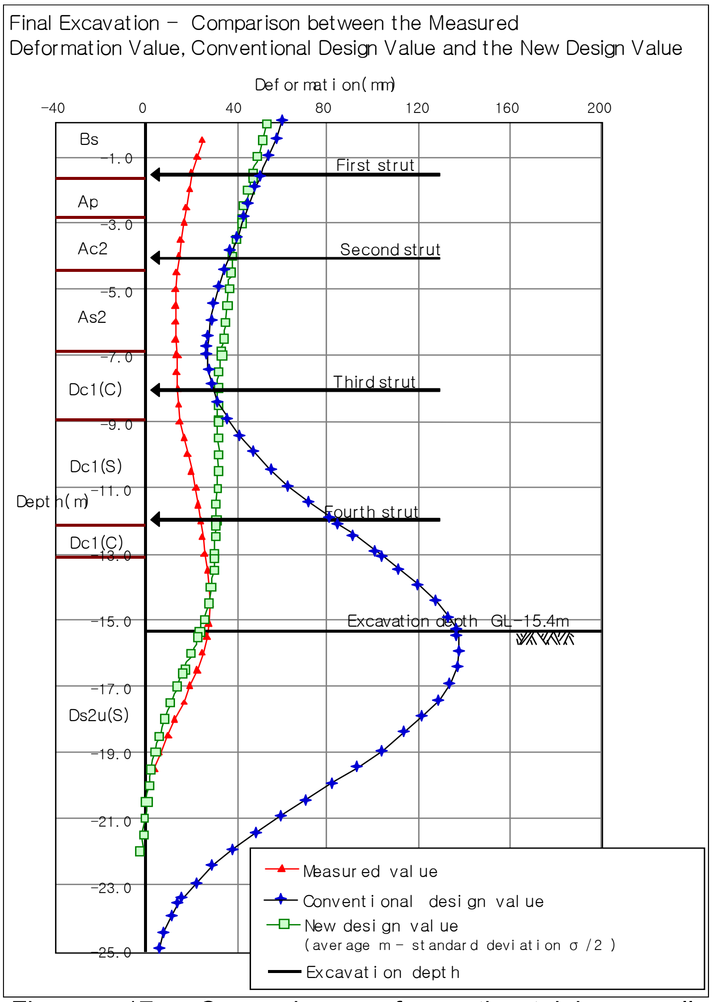


Figure 17. Comparison of earth-retaining wall deformation. (Actual value vs. calculated values using conventional method and new ground parameters)

Thus, taking the results of the above study into consideration, the ground parameters of the area to which the floor of the body is attached and which has great impact on design were set as follows:

a) All the ground parameters were determined based on the results of the triaxial compression tests obtained through boring sampling.

b) Three soil types (cohesive, intermediate, and sandy soils) were defined.

c) The values obtained by equation (2) were used for the cohesion (c) and the modulus of deformation (E) of the cohesive soil. The cohesion (c) on the passive side was reduced to be 50% of the active side.

The angle of internal friction (φ) was not expected.

d) The values obtained by equation (2) were used for the cohesion (c) and the modulus of deformation (E) of the intermediate soil. The cohesion (c) on the passive side was reduced to be 50% of the active side.

e) The values obtained by equation (2) were used for the cohesion (c), the angle of internal friction (φ), and the modulus of deformation (E) of the sandy soil. The cohesion (c) on the passive side was not reduced.

The deformation of the earth-retaining wall measured at the trial construction site and the

ones calculated based on the new ground parameters set by the above method (called as the new design values) and the conventional design values, respectively, are compared in Fig. 17.

By adopting the new design values, the overall wall deformation could be better simulated as compared to the calculation with the conventional design values, while maintaining conservative evaluation in terms of the deformation at the top of the earth-retaining wall.

10. CONCLUSIONS

The statistical processing was implemented on the results of the triaxial compression tests through boring sampling and block sampling, and the method for evaluating ground parameters used in design was reviewed. The results provided the following findings:

a) While the cohesion (c) of the diluvial sandy deposit is not normally expected, its mobilization was confirmed.

b) Many triaxial compression tests through boring sampling were conducted, and the design values were set based on the data obtained by the tests, using the average value and the standard deviation.

c) The cohesion (c) of cohesive and intermediate soils on the passive side was reduced by 50% to assure a higher level of safety, taking the strength reduction of the ground into account.

As a result of the comparison between the actual behavior of the earth-retaining walls measured at the test construction site and the calculated values based on the design values, it was found that the both values are approximately the same. The values show a higher level of safety that exceeds the measured values.

d) By using the fines content ratio, the plasticity index, and the like, specific soil types were set, and the ground parameters for each of the soil types were proposed. The results of the trial design of earth-retaining walls with the use of the proposed ground parameters confirmed that the embedment length can be shortened and the steel products can be downsized. Therefore, the construction cost relating to the earth-retaining walls can be reduced.

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